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Line-of-sight measurements for the NIF Neutron Imaging System and determination of line-of-sight offsets in OPAS 90-135 images

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Line-of-sight measurements for the NIF Neutron Imaging System and determination of line-of-sight offsets in OPAS 90-135 images

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This report describes line-of-sight (LOS) measurements for the NIF Neutron Imaging System (NIS) and a characterization of the NIS LOS relative to OPAS 90-135 that were performed during the NIS commissioning Nov. 2010 – Jan. 2011. As described here, data from those measurements were used to determine the relative offsets between the TCC position (x and y pixel coordinates in OPAS images) and the NIS LOS as functions of the OPAS focal distance. This data is needed to place the NIS pinhole array (PHA) onto the NIS LOS with high precision using OPAS imaging of alignment fiducials attached to the front and the back of the PHA. (A description of the PHA alignment fiducials, data from metrology performed on the fiducials and a description on how these fiducials were used to align the PHA for the first NIS imaging shot on Feb,. 17, 2011 will be summarized in an upcoming separate report.

This report consists of an overview given in this document and a main body that consists of a set of viewgraphs (see Appendix 1) that were iterated and refined within the NIS team and with the Alignment Working Group and that contain more detailed information, schematics and calculations of the NIS line of sight offset from the OPAS LOS. See also Drury, "OPAS 90-135 Registration of Neutron Imaging System Line of Sight," January 2011, NIF-5035484.

I. Introduction

The Neutron Imaging System (NIS) at the National Ignition Facility (NIF) is designed to capture a 2-D image of the source distribution of neutrons from imploding inertial confinement fusion capsules. The neutron imaging system consists of a pinhole camera, in which an aperture is used to define an image at a plane, and an imager or scintillating fiber array in the neutron imaging annex to NIF about 28m from TCC (slide 2). Since neutrons penetrate materials far more than photons do in optical pinhole cameras, a neutron imager requires significantly thicker pinholes, which drives strict alignment requirements, in particular in the pointing of the pinhole. (In the case of the actual NIF NIS, the aperture is actually an array of pinholes in 20-cm of gold sandwiched in tungsten. Details are described in Fittinghoff, Bower, et al., March 2011, "Stability Measurements for Alignment of the NIF Neutron Imaging System Pinhole Array," LLNL-TR-477431.)

The stated strict alignment requirements for this PHA are 1) positioning the front of the pinhole to within ±25 μm in x and y from a line from the source (TCC) to the center of the scintillator (line of sight 90-315) used to detect the neutrons, 2) pointing of the back of the pinhole to within 60 μradians of that line and 3) placing the pinhole at a known distance from the source in the z-direction to within ±250 μm.

While these requirements have been temporarily loosened (±50 μm in x and y and ±1 mm in z) for the initial imaging campaigns, achieving alignment requires high precision in the placement and pointing of the PHA (and, in addition, high stability of all the components involved in the alignment and the physical support of the PHA) – as described in Fittinghoff, Bower, et al., LLNL-TR-477431.

II. Line-of-sight measurements for the NIF neutron imaging system

As part of the NIS installation, collimators were placed in the target bay (TB) wall and in the switchyard (SY) wall (slide 2). In addition, the scintillator and corresponding imaging equipment was placed onto a laser table in the neutron-imaging annex. A precision survey was used to center the collimators on the ideal neutron imaging line of sight that extends from TCC into the direction 90-315 (a horizontal line) while the collimators were installed (mounted and grouted in). During the same precision survey the center of the scintillator was placed onto the same line. A similar precision survey was used in December 2010 to verify the actual positions of TB wall and SY wall collimators and the scintillator. The results are summarized on slide 3, which shows the measured deviations from the ideal placement in x and y and lists the actual z locations of collimator entrances and exits and the scintillator (imager).

III. Registration of the NIS LOS to OPAS 90-135

Since OPAS 90-135 is the most important tool to align the NIS PHA to the NIS LOS, it is important to understand the OPAS LOS in relationship to the NIS LOS. Ideally, OPAS 90-135 should also have its LOS along the 90-315 direction. In practice, however, there is a subtle difference between the OPAS 90-315 LOS (slides 4 and 5) that was further characterized in the registration of the NIS LOS to OPAS 90-135 performed on Jan. 19, 2011 (slides 6-12). Slide 7 shows a summary of the results, whereas slide 8 shows the corresponding OPAS registration to TCC using the target alignment sensor (TAS) and slides 9-12 show the OPAS images of the individual target (target plate, in this case) locations.

In the following analysis of the data from the NIS LOS to OPAS registration several assumptions are made that are listed on slides 13-14. Most notably, slide 13 lists an equation that is used to calculate the effective OPAS image pixel size as function of z (the distance from TCC). This equation was provided by Stacie Manuel and Tom McCarville. It stems from their characterization of the OPAS camera and imaging system during OPAS 90-135 commissioning. Slide 15 summarizes the survey and NIS LOS to OPAS registration data. Slide 16 lists the inputs for the straight-line fits that were used to describe the relative offset of the OPAS LOS from the NIS LOS as function of z. These fit inputs (Delta_x corrected and Delta_y corrected) take the measured actual survey target offsets from the ideal line 90-315 into account. Slides 17 and 18 show the results of the fits for the x offset and y offset, respectively.

From the results of these fits, the NIS LOS offsets from the OPAS LOS are calculated. This is first done in mm space (slide 19), then converted to corresponding OPAS pixels (slide 20) taking into account the change in effective OPAS image pixel size as z increases. (Note that the definition of positive x and y in the precision survey and thus the mm space is different from the definition of positive (increasing) x and y pixel numbers – as indicated by the small coordinate system icons on slides 15-20. For example, a negative y pixel offset between NIS LOS and OPAS LOS (slice 20) means the NIS LOS is *above* the TCC pixel in the OPAS image (and thus higher up and at larger y in mm space). Given that the NIS LOS is essentially a horizontal line this means the OPAS LOS is pointing down slightly.)

For the location of the front and back of the NIS PHA (z=0.325 m and z=0.525 m, respectively, as used for the first NIF NIS imaging shot on 2/17/11), we find the NIS LOS offsets from the OPAS 90-135 LOS and TCC pixel to be -4.66 and -7.30 pixels in x, respectively, and to be -47.4 and -74.3 pixels in y, respectively.

IV. Effects of Re-registration of OPAS 90-315 to TCC

As a matter of practical experience, the effective TCC pixel in the OPAS 90-315 images changes slightly as the OPAS is re-registered to TCC, periodically, using TAS. Originally attributed to potential small shifts in the OPAS LOS, more recent measurements (multiple registrations over the course of days) performed during the NIS commissioning and PHA alignment for the first neutron imaging shot on 2/17/11 indicate that OPAS seems very stable (e.g., relative to the aligned PHA) and that the observed pixel shift in registration to TCC may have other causes related to how TCC is defined using TAS. In one instance, for example, the re-registration of OPAS to TCC after less than a day (2/14-2/15/11) was found to change the expected position of target chamber center (TCC) by 13 pixels (>200 μm) in x. While the NIS system was determined to be sufficiently stable relative to the OPAS cameras and the target, the potential position of the target placement could be far outside the tolerances for NIS (Fittinghoff, Bower, et al., LLNL-TR-477431).

To deal with this problem of drifting OPAS TCC registration, the alignment sequence was changed to include a final alignment of the NIS pinhole to the target after the final OPAS registration to TCC. In this final alignment step, the new TCC pixel x-y coordinates are used together with the previously calculated NIS LOS x and y pixel offsets for front and back of the PHA (slide 22). In essence, the PHA is translated slightly, if necessary, to point at the newly defined TCC, while keeping the PHA at the same angle in space (keeping the same angular offset). This ensures that the PHA is pointing at TCC (the most stringent requirement) while still pointing at the scintillator albeit at a small offset from the scintillator center – the offset corresponding to the slight translation of the PHA performed in this final alignment step (slide 23).

V. Conclusions

The alignment system for the National Ignition Facility's neutron imaging system has been commissioned. As part of this commissioning work, the NIS LOS has been characterized by precision surveys, and the angular offset between the OPAS 90-135 LOS has been determined. Knowing the angular offset and assuming both NIS LOS and OPAS LOS pass through TCC, the x-y offset of the NIS LOS from the OPAS LOS as function of distance z from TCC was calculated in mm space (determined by a fit) and expressed in effective OPAS pixels using a predetermined expression for the effective OPAS image pixel size as function of z. Using the calculated desired pixel offsets for the front and back center of the PHA, the PHA was successfully placed onto the NIS LOS and the first neutron image from a NIF shot was obtained on 2/17/11. The OPAS registration to TCC and thus the x-y pixel corresponding to TCC in the OPAS image drifts slightly over time. The current PHA alignment strategy is to correct for those drifts by slightly translating the PHA in x and y while keeping its angular alignment unchanged. This ensures that the PHA is pointing to TCC while causing only a small (acceptable) shift in the image on the scintillator.

A re-registration of the NIS LOS using another precision survey and OPAS should be considered on a 6-12 month timescale (slide 24) to determine any long-time drifts in NIS LOS (e.g., by subtly long-term movement of the building) and to investigate the long-term stability of OPAS.

VI. Appendix 1—Presentation Materials

NIC

Neutron Imaging System Line of Sight Commissioning Report

March 31, 2011

Matthias Frank, David Fittinghoff, Dan Bower, Owen Drury, John Dzenitis, Robert Buckles, Carl Wilde, Carter Munson

Lawrence Livermore National Laboratory • National Ignition Campaign

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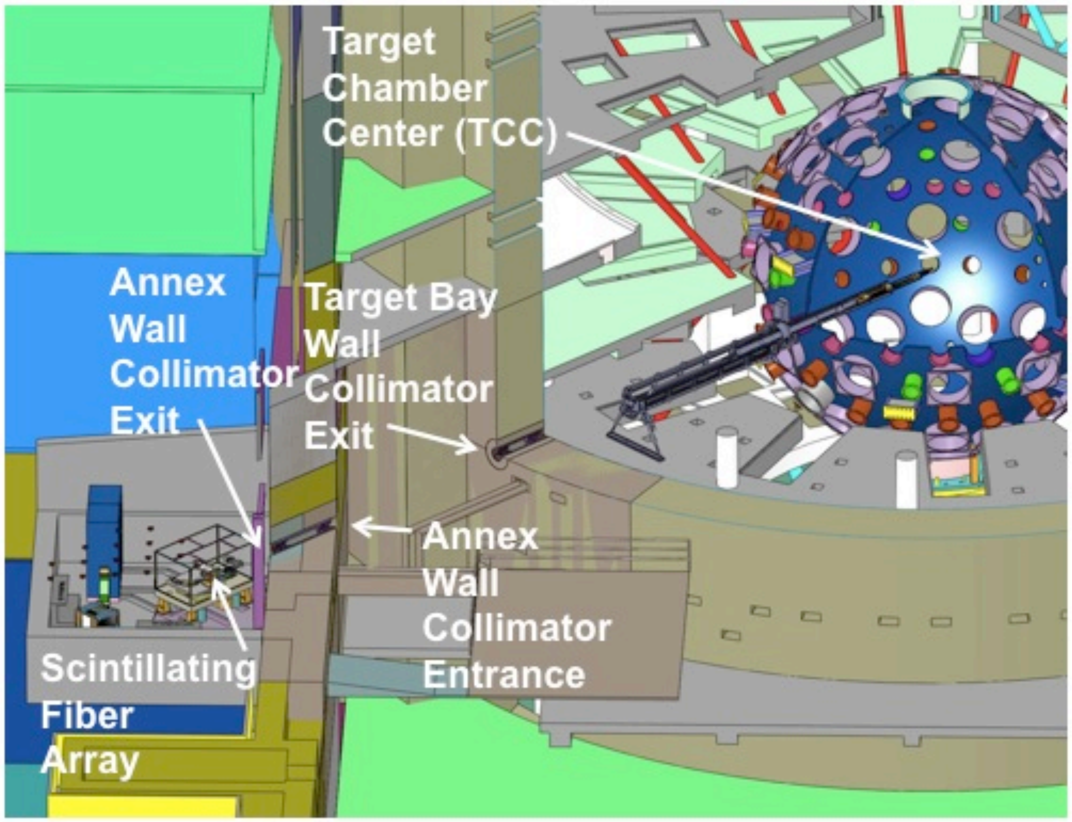
NIC

Neutron Imaging Line of Sight OPAS Image Locations



2

NIS LOS Registration with Precision Survey Dec.10

- SMR survey targets were mounted to target mounts inserted into the center of the TB wall collimator (both ends) and the center of the SY wall collimator (both ends). In addition, a survey target was placed over the center of the imager in the annex.
- Goal of the survey was to measure how well centered the collimators and the imager were with respect to the ideal NIS LOS 90-315

- Results:

Target Locations:	X [mm]	Y [mm]	Z [mm]
TB1	0.021	0.159	15394.821
TB4	-0.104	-0.239	17044.888
SY1	-0.466	-0.393	23447.831
SY4	-0.871	0.204	25609.808
IMAGER	0.179	-0.358	27979.231

(where is this data archived?)

Note that the survey uses a right-handed coordinate system centered at TCC (0,0,0) where z is out (away from TCC), y is up and x, consequently, is to the left as seen from TCC when looking towards the imager.

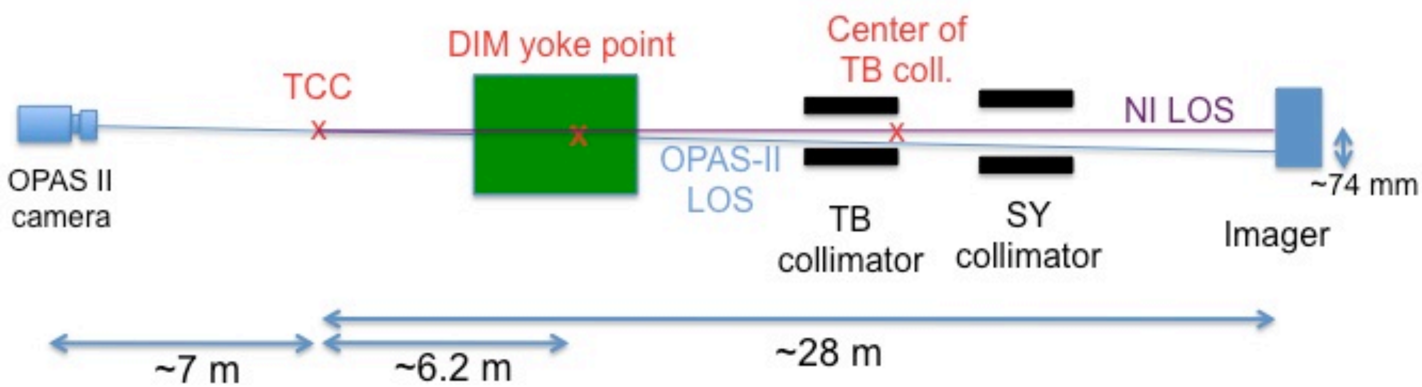
3

NIS alignment procedure needs to take into account that OPAS LOS and NI LOS are not exactly the same

NI LOS is close to, but not identical to OPAS LOS (the latter being defined by a line through TCC and the "DIM yoke point")

The main constraint is that objects along NI LOS need to be in the OPAS FOV

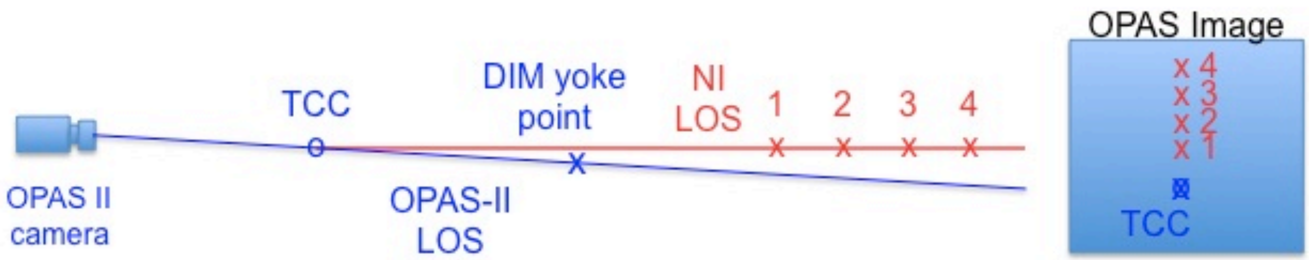
- Previous estimates assumed DIM yoke point is low (with respect to NI LOS) by 6 mm resulting in OPAS LOS being low by ~27 mm at the imager.
- More recent work described here indicates that OPAS LOS is ~74 mm low at the imager (corresponding to DIM yoke point being low by ~16 mm).
- Still good to go because OPAS FOV is large at imager (~570 mm)



4

NIS alignment procedure needs to take into account that OPAS LOS and NI LOS are not exactly the same

Objects aligned to a line (such as NI LOS) that is offset and/or at an angle relative to the OPAS LOS appear in different locations (pixels) in the OPAS images depending on their distance from OPAS (i.e., OPAS focal distance)



- This is related to OPAS magnification changing with focal distance and NI LOS and OPAS LOS intersecting at TCC (and not OPAS)
- As a result, objects exactly aligned to NI LOS should appear in slightly different positions (pixels) in the OPAS image as OPAS focus is changed from object to object along this line
- This effect was further characterized during NIS commissioning Jan. 19, 2011 before OPAS was used to align the NIS pinhole for the first neutron imaging shot
- The results of this characterization are summarized here.

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NIS LOS Registration with OPAS 90-135 01/19/10

- Target mounts (but not the SMR targets) were re-inserted into the center of the TB wall collimator (just the SY side end – to simplify and accelerate procedure) and the center of the SY wall collimator (both ends) for registration with OPAS. In addition, a target plate (without the SMR target) was placed over the center of the imager in the annex.

- Goal of the OPAS registration was to measure where in the OPAS image the centers of the collimators and the center of the imager appear and to use that data to calculate more generally where in the OPAS image the NIS LOS is located for any given focal distance (NIS LOS pixel coordinates as function of z).

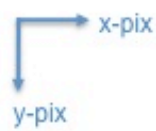
Results of NIS LOS Registration with OPAS 90-135 01/19/10

Using OPAS to view fiducials on TAS and calculating TCC position – as is commonly done when OPAS is registered to TCC – TCC was found to be at

TCC: (x_pix, y_pix) = (3970.5,2983.5) z=0 by definition

The centers of the target plates were found to be at

	x pixel, y pixel	z [m]
TB4	3907, 2297	17.0087
SY1	3900, 2236	23.4620
SY4	3901, 2217	25.5736
IMAGER	3896, 2207	27.9934



Note that OPAS x_pixel number increases to the right and y_pixel number increases downward

Here, z is not from OPAS but from precision survey, corrected for any known standoff distance of the SMR target (used in precision survey) from target plate (that was viewed by OPAS) – corrections were determined by Owen Drury based on drawings of targets and plates - see OD email 2/2/11 and the following images 7

NIC

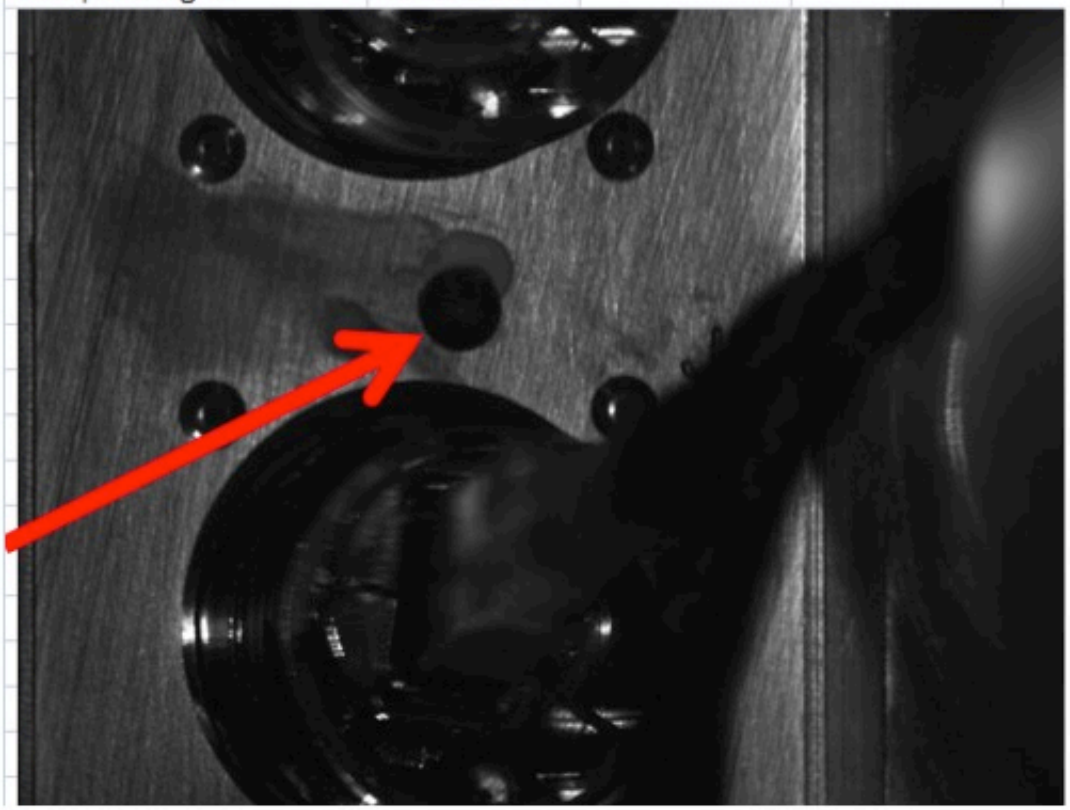
Target Chamber Center Registration

OPAS pixel

- X=3970.5
- Y=2983.5

- Z=0

Sample images and data analysis	
Example images	OPAS 90-135



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NIC

Target Bay Wall Collimator Exit (TB4) Image

OPAS pixel

- X=3907
- Y=2297

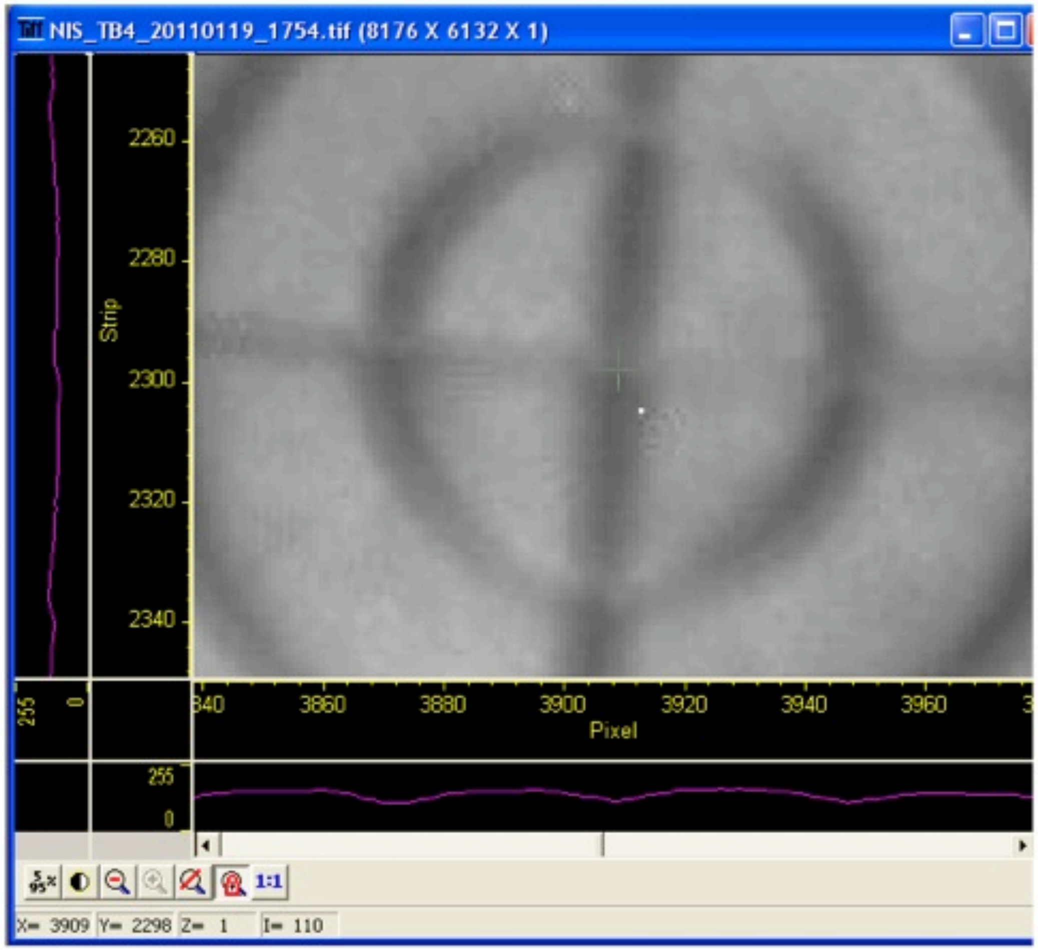
Target plate

- Z=17.0087m

SMR target position (from precision survey)

- Z=17.0449 m

(note the target plate is 36.2 mm closer to TCC than the SMR target was – O. Drury determined this z correction from drawings 2/2/11)



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Annex Wall Collimator Entrance (SY1) Image

OPAS pixel

- X=3900
- Y=2236

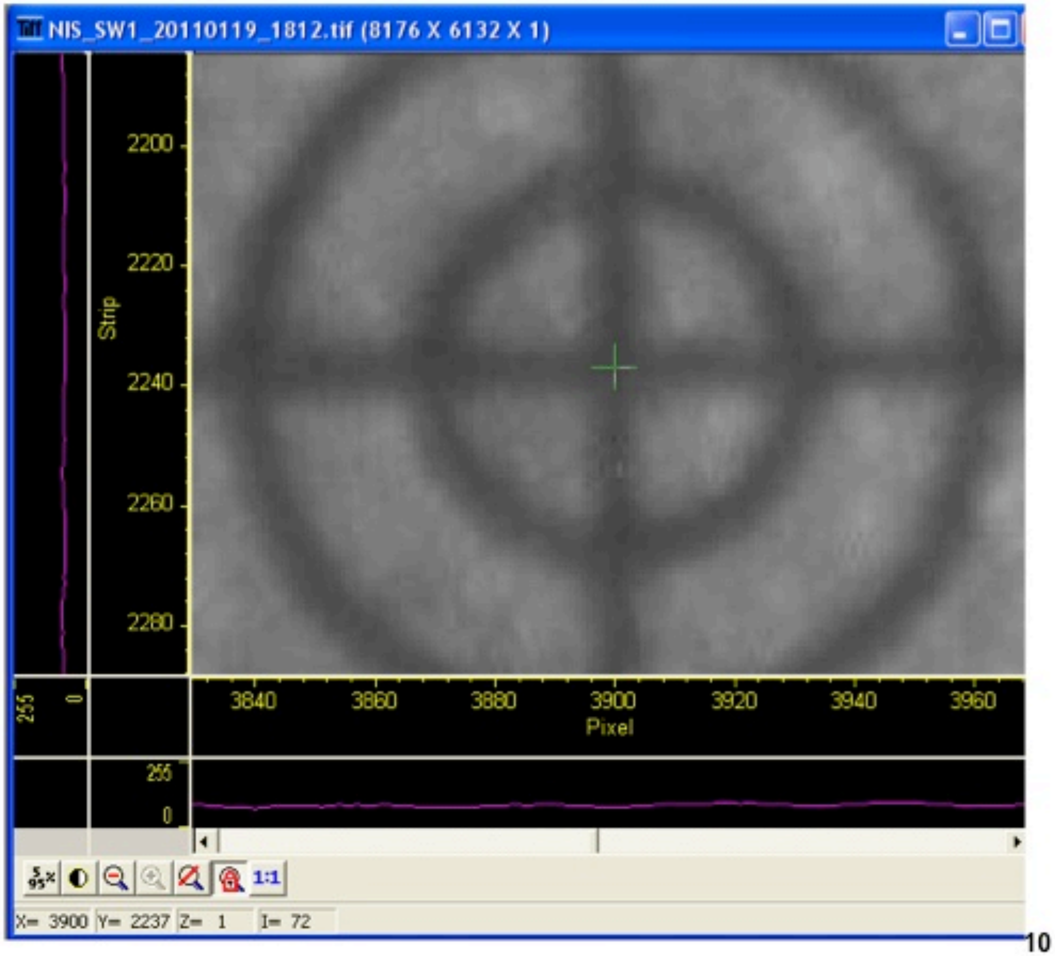
Target plate

- Z=23.4620 m

SMR target position (from precision survey)

- Z=23.4478 m

(note the target plate is 14.2 mm further from TCC than the SMR target was)



Annex Wall Collimator Exit (SY4) Image

OPAS pixel

- X=3901
- Y=2217

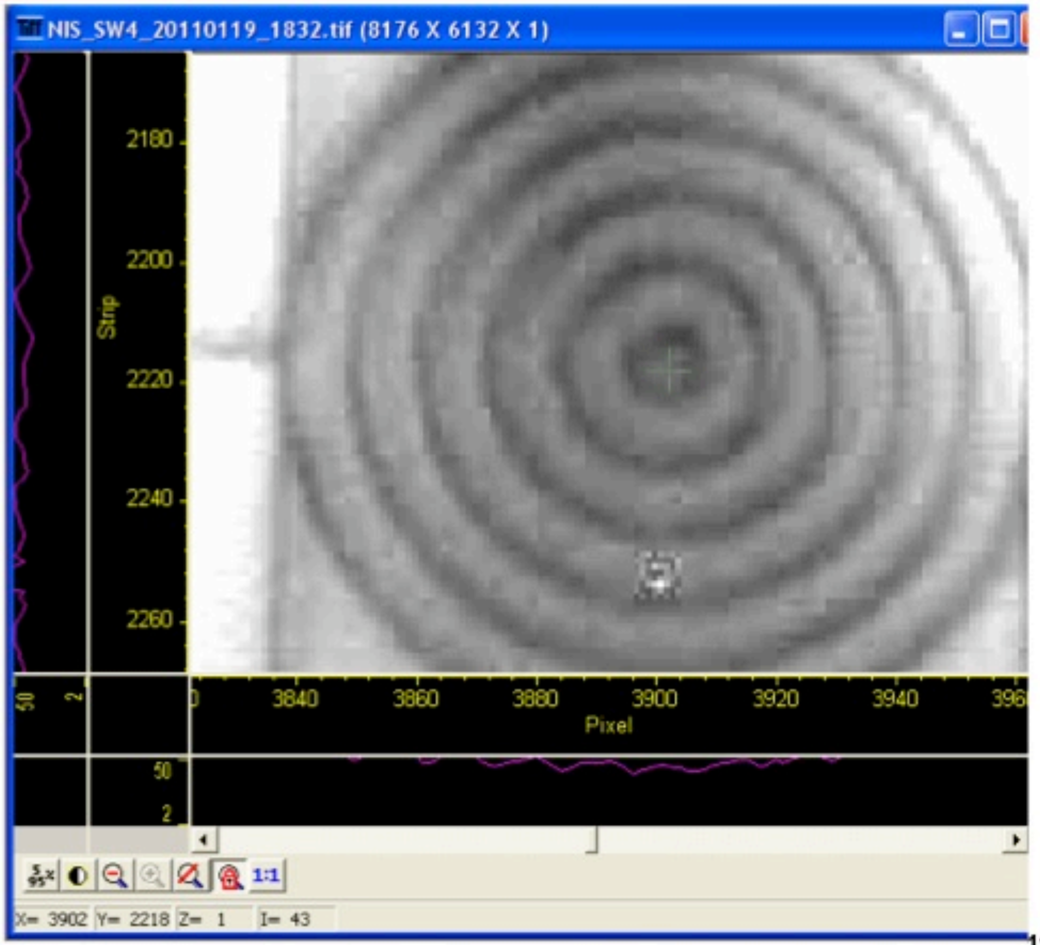
Target plate

- Z=25.5736 m

SMR target position (from precision survey)

- Z=25.6098 m

(note the target plate is 36.2 mm closer to TCC than the SMR target was)



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NIC

Scintillating Fiber Array (SCINT) Image

OPAS pixel

- X=3896
- Y=2207

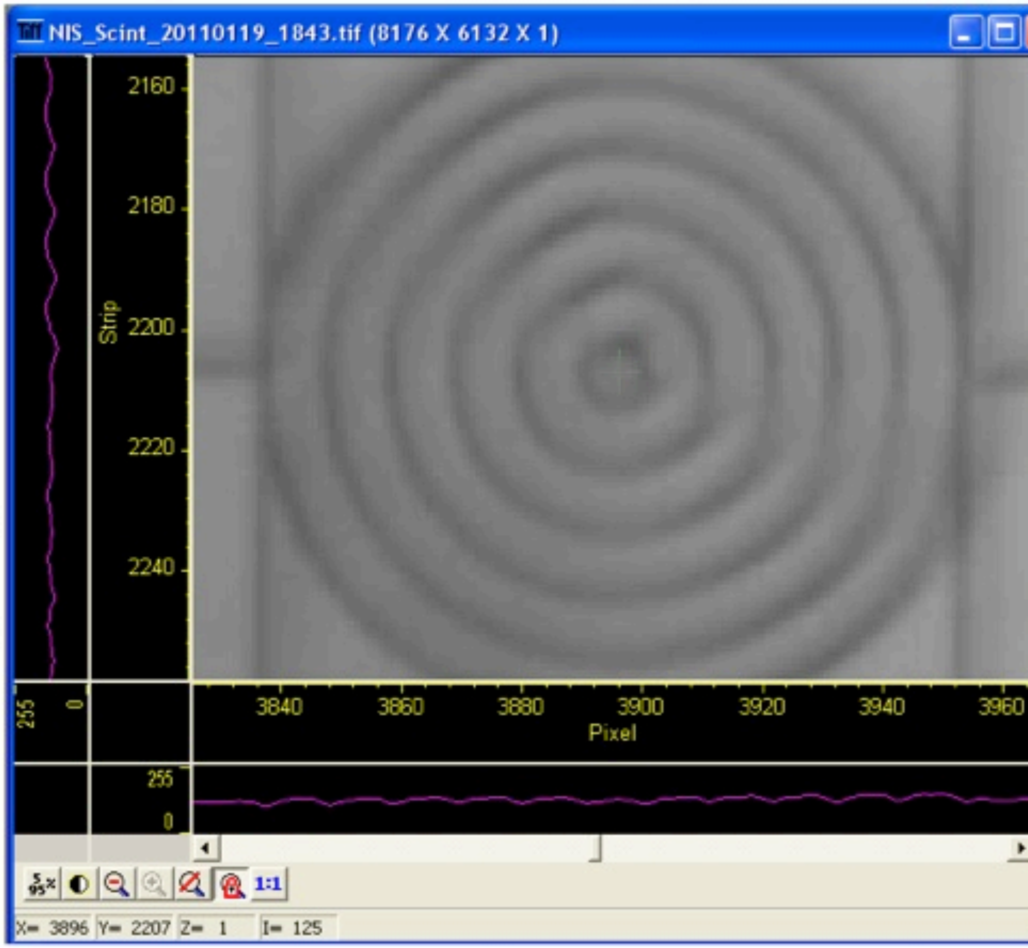
Target plate

- Z=27.9934 m

SMR target position (from precision survey)

- Z=27.9792 m

(note the target plate is 14.2 mm further from TCC than the SMR target was)



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Assumptions and Inputs

- OPAS LOS is a straight line that goes through TCC and is offset from the ideal, horizontal line (90,315) in x and y
  - The vertical offset can be described by y_offset = a*z + 0, where a is the y slope of the OPAS LOS and the constant in this equation for the straight line is zero because it goes through TCC defined as (x=0,y=0,z=0)
  - y offset was originally estimated to correspond to ~6 mm at DIM 90-315 yoke point (~6.2 m from TCC) corresponding to a slope of ~1000 um/m
  - The analysis below will show that this offset is closer to ~16 mm at the DIM yoke point corresponding to a slope of ~2670 um/m

  - For our purposes, this slope does not need to be known beforehand but can be obtained from the fit of the NIS LOS OPAS registration data

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Assumptions and Inputs (cont'd)

- OPAS pixel size as function of z (distance from TCC) can be obtained from

$$\text{pixel\_size [um]} = 6 * (0.4633 * z[m] + 2.8658) = 2.7798 * z[m] + 17.1948$$

  - equation from Stacie Manuel
  - a similar function can be obtained from the image data (Carter Munson)

- The OPAS LOS offset from the NIS LOS as function of z and expressed as OPAS pixels is given by

$$\text{y\_offset [pix]} = \text{y\_offset [um]} / \text{pixel\_size[um]} = a*z[m] / (2.7798*z[m] + 17.1948)$$

  - a similar equation exists for the x_offset (parameter b describing slope in x)
  - these equations for x_offset and y_offset are used below to fit the registration data and determine parameters a and b that will allow to calculate where in the OPAS images the NI LOS is as function of z

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Measured OPAS and Precision Survey Data

	y, z, x	x-pix, y-pix	x-pix, y-pix	x-pix, y-pix	x-pix, y-pix	y, z, x	y, z, x
	z [m] (pix_size [um])	OPAS x-pixel	OPAS y-pixel	Delta_x [pix]	Delta_y [pix]	Delta_x [mm]	Delta_y [mm]
TCC	0.0 (17.1948)	3970.5	2983.5	0.0	0.0	0.0	0.0
TB4	17.0087 (64.4756)	3907	2297	-63.5	-686.5	4.0942	44.2625
SY1	23.4620 (82.4145)	3900	2236	-70.5	-747.5	5.81022	61.6048
SY4	25.5736 (88.2843)	3901	2217	-69.5	-766.5	6.13576	67.6699
SCINT	27.9934 (95.0109)	3896	2207	-74.5	-776.5	7.07831	73.7759

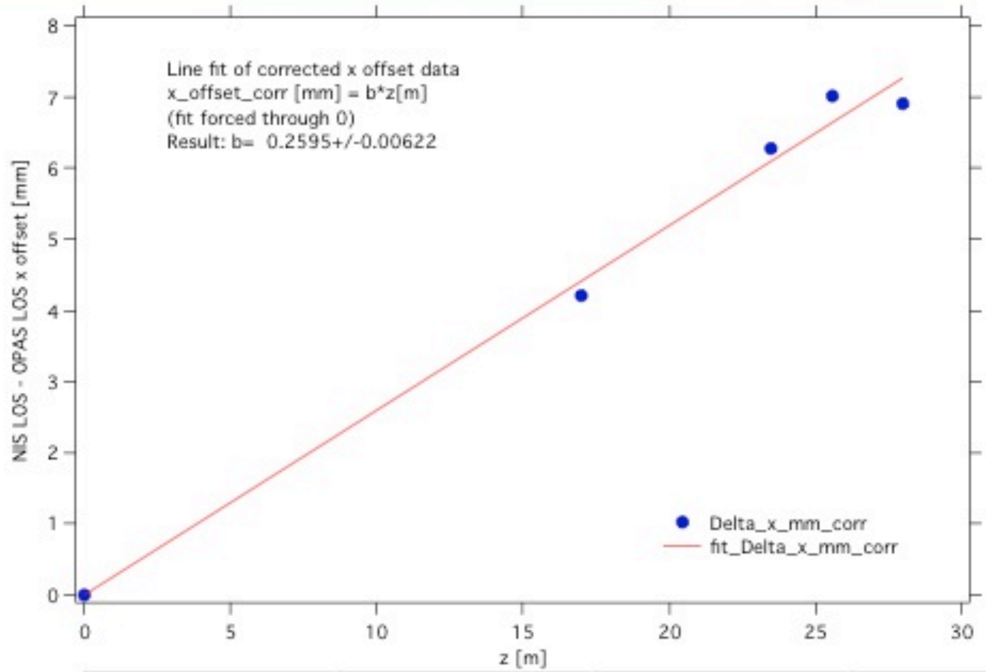
Delta_x [mm], Delta_y [mm] here are calculated from OPAS pixels and pixel size

Measured OPAS and Precision Survey Data: Fit Inputs

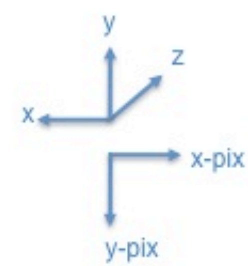
					
	z [m] (pix_size)	Survey Target x-offset from ideal [um]	Survey Target y-offset from ideal [um]	Delta_x corrected [mm]	Delta_y corrected [mm]
TCC	0.0 (17.1948)	0.0	0.0	0.0	0.0
TB4	17.0087 (64.4756)	-104	-239	4.1982	44.5015
SY1	23.4620 (82.4145)	-466	-393	6.27622	61.9978
SY4	25.5736 (88.2843)	-871	204	7.00676	67.4659
SCINT	27.9934 (95.0109)	179	-358	6.89931	74.1339

The corrected Delta_x and Delta_y take into account the offsets from the ideal LOS as measured by the precision survey

Fit to Corrected **x** LOS offset data



NIS LOS is to the left of OPAS LOS (looking away from TCC towards Scintillator)



z [m]	calc. x offset [um] from fit	pixel size [um]	OPAS x pixel offset
0.325	+84.3375	18.0982	-4.66
0.525	+136.237	18.6542	-7.30

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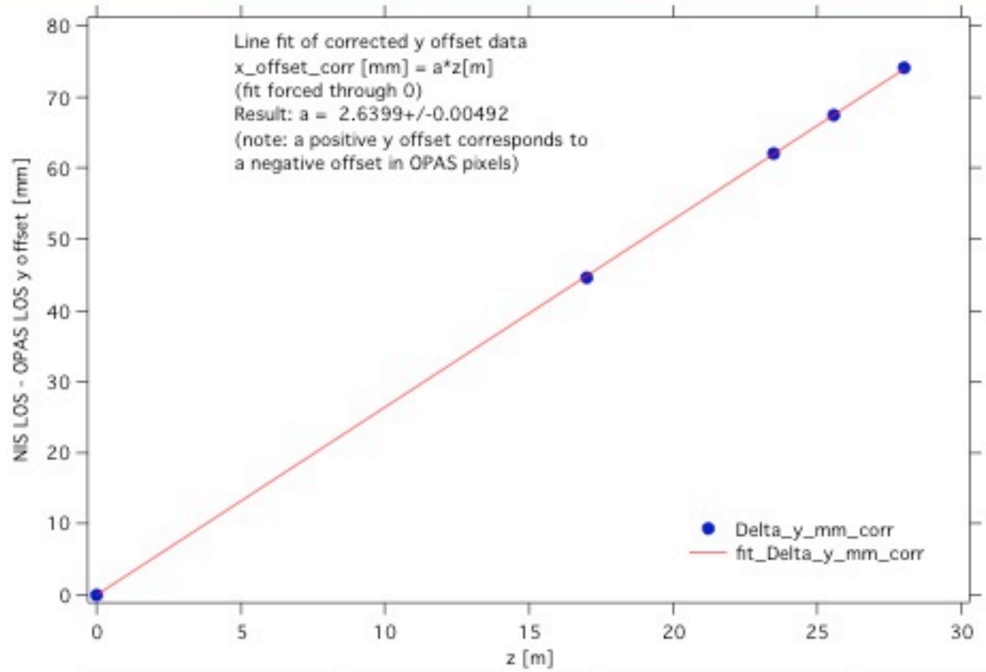
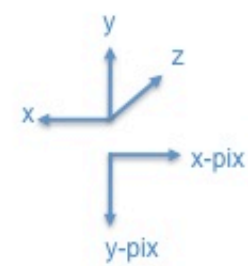
Fit to Corrected **y** LOS offset data



NIS LOS is above OPAS LOS



z [m]	calc. y offset [um] from fit	pixel size [um]	desired OPAS y pixel offset
0.325	857.967	18.0982	-47.4
0.525	1385.948	18.6542	-74.3

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Neutron Imaging Line of Sight [mm] Offsets

	z [m] (pix_size)	Delta_x corrected [mm]	Delta_x from fit [mm]	Delta_y corrected [mm]	Delta_y from fit [mm]
TCC	0.0 (17.1948)	0.0	0.0	0.0	0.0
Front PHA	0.325 (18.0982)		0.0843375		0.857967
Back PHA	0.525 (18.6542)		0.136237		1.385948
TB4	17.0087 (64.4756)	4.1982	4.41376	44.5015	44.9013
SY1	23.4620 (82.4145)	6.27622	6.08839	61.9978	61.9373
SY4	25.5736 (88.2843)	7.00676	6.63635	67.4659	67.5115
SCINT	27.9934 (95.0109)	6.89931	7.26429	74.1339	73.8998

NIS LOS (x,y) offset relative to OPAS LOS is (1.6 mm,16.2 mm) at DIM yoke point (6.2 meters) – OPAS LOS is low and right of NIS LOS

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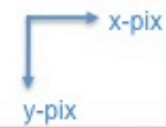
Neutron Imaging Line of Sight Pixel Offsets



	z [m] (pix_size)	Delta_x [pix] calculated from Delta_x_corr	Delta_x calculated from fit [pix]	Delta_y calculated from Delta_y_corr	Delta_y calculated from fit [pix]
TCC	0.0 (17.1948)	0.0	0.0	0.0	0.0
Front PHA	0.325 (18.0982)		**-4.66**		**-47.4**
Back PHA	0.525 (18.6542)		**-7.30**		**-74.3**
TB4	17.0087 (64.4756)	-65.11	-68.4563	-690.21	-696.407
SY1	23.4620 (82.4145)	-76.15	-73.8752	-752.27	-751.535
SY4	25.5736 (88.2843)	-79.37	-75.1701	-764.19	-764.708
SCINT	27.9934 (95.0109)	-72.62	-76.4574	-780.27	-777.804

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Impact of Re-registration of OPAS to TCC on pinhole alignment?

- As part of NIS LOS measurements Jan. 19, 2011 OPAS (90-315) was registered to TCC
  - TCC was found to be at (x,y) = (3970.5pix,2883.5pix) in the OPAS image
- As OPAS is re-registered to TCC over time, pixel corresponding to TCC may change
  - It is unclear whether such a shift corresponds to an actual change in TCC location or just a slight shift in OPAS LOS (translation and/or tilt) or both
  - TCC was found to be at (x,y) = (3946pix,2924pix) on 2/14
  - TCC was found to be at (x,y) = (3933pix,2935pix) on 2/15
  - TCC was found to be at (x,y) = (3932pix,2932pix) on 2/16
- PHS alignment numbers (=desired pixel locations of fiducials) should be adapted to ensure pinhole is pointed at TCC
  - pointing pinhole at scintillator at the same time is a less stringent requirement because the scintillator area is larger than the expected image, i.e., there is some slack

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Adapting pinhole alignment numbers to re-registration of OPAS to TCC

- Original NIS + OPAS LOS characterization 1/19 measured the angular offset of NIS and OPAS LOS
  - Fit to mm offset data shows that vertical offset corresponds to 16.3 mm at 6.2m, i.e, 2.63 mm/m (OPAS LOS low with respect to NIS LOS); x offset X10 smaller
  - this is reflected in the calculated desired pixel offsets of fiducials at front and back of the pinhole
- If OPAS registration to TCC changes, use the new TCC pixel coordinates and keep the same angular offset of the NIS LOS
  - this will ensure TCC, front center of pinhole and back center of pinhole are on the same line, i.e., the pinhole is pointing at TCC
  - this will result in a corresponding shift of the image on the scintillator
  - Example: if the OPAS TCC pixel (x or y) changes by, say, 50 pixels (corresponding to 0.86 mm at TCC) and the pinhole is adjusted accordingly this results in the same shift of the image at the scintillator, which is still o.k.
  - see illustration next slide
- Upon obtaining an updated OPAS registration (new TCC pixel locations) use the calculated (relative) desired pixel offsets from TCC to update desired fiducial or average_x,y locations

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Final PHA adjustment if OPAS registration to TCC changes upon OPAS re-registration short before a shot: translation only preserves angular pointing at TCC

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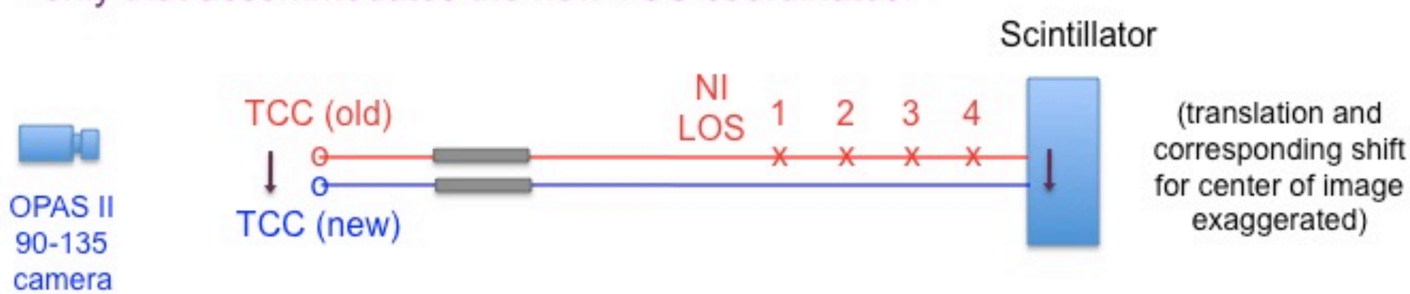
- OPAS may be re-registered to TCC (using TAS) during the final alignment of the NIS PHA
- It has been observed that OPAS pixel numbers corresponding to TCC may change by a few pixels during this re-registration (corresponding also, presumably, to a new location for the NIF target)
- In fine tuning the PHA alignment, the highest priority is to maintain PHA point at TCC
- This is achieved by limiting the final alignment of the PHA to a translation only that accommodates the new TCC coordinates.



- This operation will shift (translate) the center of the neutron image on the scintillator by same distance the PHA is translated – e.g. for a 10 pixel shift in OPAS to TCC registration this would correspond to a ~170 um translation.

Future re-registration of NIS LOS?

Experience during NIS alignment commissioning

- OPAS registration to TCC drifted typically several pixels between registrations (worst case was a ~13 pixel shift within less than 24 hours 2/14-2/15/11)
- OPAS' view of NIS pinhole and fiducials, however, appeared much more stable. Upon further investigation it seems likely this shift can be attributed to how TCC is registered using TAS. OPAS appears more stable than initially thought.

Re-registration of NIS LOS using another precision survey and OPAS should be considered on a 6-12 months timescale

- to determine any long-term drifts in LOS (caused, e.g., by subtle long-term movements of building)
- to determine long-term stability of OPAS

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